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(54) Title: RESERVOIR ACQUISITION SYSTEM WITH CONCENTRATOR

(57) Abstract

A process comprising: transmitting remote data signals independently from each node of the plurality of permanently coupled remote sensor nodes to a concentrator of the data signals; and transmitting concentrated data signals from the concentrator to a recorder. A reservoir monitoring system comprising: a plurality of permanently coupled remote sensor nodes; a concentrator of signals from the plurality of permanently coupled remote sensor nodes; and a recorder of concentrated signals from the concentrator. A reservoir monitoring system comprising: a plurality of permanently coupled remote sensor nodes, wherein each node comprises a plurality of seismic sensors and a digitizer of analog signals; a concentrator of signals received from the plurality of permanently coupled remote sensor nodes; a plurality of remote transmission lines which independently connect each of the plurality of remote sensor nodes to the concentrator; a recorder of concentrated signals from the concentrator; and a transmission line which connects the concentrator to the recorder.

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RESERVOIR ACQUISITION SYSTEM WITH CONCENTRATOR

TITLE OF THE INVENTION

RESERVOIR ACQUISITION SYSTEM WITH CONCENTRATOR

FIELD OF THE INVENTION

This invention relates generally to data acquisition and telemetry communication methods and systems, and more particularly, to processes and apparatuses for conducting long-term seismic surveys.

BACKGROUND OF THE INVENTION

Seismic surveys have been used for several years to locate and evaluate new mineral reservoirs. More recently, seismic survey technology is being used to monitor production reservoirs for enhancement of production processes. Accurate comparison data, taken at various stages during production, requires that subsequent seismic surveys be conducted in exactly the same manner as previous surveys. For example, seismic sources and receivers must be located and coupled to the earth similarly for each survey conducted. The best way to ensure similar locality and coupling is to permanently install seismic receivers in the earth, so that they may be used to produce similar seismic surveys at various intervals over a long period of time. Prior seismic receiver systems are based on either analog or digital transmission schemes.

As shown in Figure 1, prior analog systems consist of sensors 1, 2, 3, . . . N, which are attached directly to a central recording unit 13. Typically, analog systems provide independent circuitry between each sensor and the central recording unit 13 so that not all sensors are lost if one circuit fails. However, these systems are expensive because of the numerous cables which must extend over great distances from the remote sensors to the central recording unit 13. Most especially in offshore applications, the heavy cables necessary for independent circuitry render large monitoring systems impractical. Further, analog signals may only be transmitted short distances. These transmissions also provide limited channel capacity and poor data quality. Therefore, in the past, analog receiver

systems have only been used in temporarily installed land, transition zone systems or towed offshore systems.

Digital systems have also been used in the seismic industry. For example, U.S. Patent No. 5,450,369, issued to Mastin et al. on September 12, 1995; U.S. Patent No. 5,058,080, issued to Siems et al. on October 15, 1991; and U.S. Patent No. 4,648,083, issued to Giallorenzi on March 3, 1987, all incorporated herein by reference, disclose digital systems in offshore streamer applications. As shown in Figure 2, prior digital systems comprise a plurality of sensor nodes 11 connected in series. Each sensor node 11 consists of several sensors 1, 2, 3, . . . N, a collector/digitizer 20 and transmission lines 14 for transmitting the analog signals from the sensors 1, 2, 3, . . . N to the collector/digitizer 20. All of the sensor nodes 11 are then connected in series via a common transmission and power cable 4 to a central recording unit 13. The number of wires required to transmit the data from the sensors to the central recording unit 13 is reduced to a single cable. This single cable 4 may transmit data to nearly unlimited distances without sacrificing the quality of the data transmitted. Also, digital systems provide increased channel capacity. However, prior digital systems are not entirely conducive to permanent installation for long-term monitoring of production mineral reservoirs. Since all sensor nodes in a digital system depend upon a common power and transmission line, the entire system fails if the transmission line becomes damaged. Where the sensor nodes are buried in the earth or permanently installed on a sea floor, it is extremely costly to recover the damaged portion of the transmission line for repair. Further, if the cable is removed for repair, it is unlikely that the replacement cable will be placed in exactly the same position to enable similar seismic surveys as obtained with the first cable. Therefore, these prior digital systems, which have only been used in streamer applications or applications where the sensor cables are easily accessible, are not conducive to long-term reservoir monitoring applications.

Alternative systems have been developed which incorporate basic elements of analog and digital transmission systems. For example, U.S. Patent No. 5,253,219, issued to Houston et al. on October 12, 1993, incorporated herein by reference, discloses a sequence of vertically aligned seismic receivers, the analog outputs from which are sequentially analog

sampled and time multiplexed onto a common pair of data conductors in the support and transmission cable. Also, U.S. Patent No. 4,599,745, issued to Baran et al. on July 8, 1986, incorporated herein by reference, discloses an apparatus having both an optical communications link and a radio frequency link. Like typical digital systems, these systems are unreliable in permanent applications because there is no independent circuitry to each of the receiver nodes.

As discussed above, previous analog, digital and hybrid systems are not conducive to a permanently installed production reservoir monitoring application. Therefore, there is a need for a seismic sensor receiver system which incorporates the desirable characteristics of a digital system as well as the independent circuitry of an analog system, so that the sensor nodes may be permanently coupled to the earth.

SUMMARY OF THE INVENTION

An object of the present invention is to provide a permanent, long-term, seismic sensor receiver system which provides a reduced number of transmission wires, high channel capacity, high data quality, long distance transmission capability, and independent circuitry to the sensor nodes.

According to one aspect of the invention, there is provided a process comprising: transmitting remote data signals independently from each node of the plurality of permanently coupled remote sensor nodes to a concentrator of the data signals; and transmitting concentrated data signals from the concentrator to a recorder.

According to another aspect of the invention, there is provided a reservoir monitoring system. In one embodiment, the system comprises: a plurality of permanently coupled remote sensor nodes; a concentrator of signals from the plurality of permanently coupled remote sensor nodes; and a recorder of concentrated signals from the concentrator.

According to a second embodiment of this aspect, there is provided a system comprising: a plurality of permanently coupled remote sensor nodes, wherein each node comprises a plurality of seismic sensors and a digitizer of analog signals; a concentrator of signals received from the plurality of permanently coupled remote sensor nodes; a plurality of

remote transmission lines which independently connect each of the plurality of remote sensor nodes to the concentrator; a recorder of concentrated signals from the concentrator; and a transmission line which connects the concentrator to the recorder.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention is better understood by reading the following description of nonlimitative embodiments with reference to the attached drawings, wherein like parts in each of the several figures are identified by the same reference character, which are briefly described as follows:

FIG. 1 is a diagram of a prior art analog receiver system typically used in temporary land, transition zone, or towed marine applications.

FIG. 2 is a diagram of a prior art digital receiver system typically used in towed marine applications.

FIG. 3a is a side view diagram of an embodiment of the present invention in which a concentrator collects data signals from remote sensors for transmission to the recorder.

FIG. 3b is a side view diagram of an embodiment of the present invention in which a concentrator collects data signals from remote sensors for transmission to the recorder, wherein the sensors of the various sensor nodes are interspersed.

FIG. 4a is a side view diagram of an embodiment of the present invention with the sensors in a permanent covered trench arrangement.

FIG. 4b is a side view diagram of an embodiment of the present invention with the sensors in a permanent pylon arrangement.

FIG. 5 is a side view diagram of an embodiment of the invention with the sensors oriented in vertical columns.

FIG. 6 is a top view diagram of an embodiment of the invention comprising concentrators and a super concentrator.

FIG. 7 is a process outline of an embodiment of the present invention for transmitting remotely received data to a central recorder.

It is to be noted, however, that the appended drawings illustrate only typical embodiments of the invention and are, therefore, not to be considered a limitation of the scope of the invention which includes other equally effective embodiments.

DETAILED DESCRIPTION OF THE INVENTION

Referring to Figure 3a, a side view diagram of one embodiment of the present invention is shown for an offshore application. Remote sensor nodes 11 are buried beneath the sea floor 17. Each sensor node 11 comprises: a plurality of sensors 10, a collector 20, and transmission wires 14, which connect each of the sensors 10 to the collector 20. The sensor nodes 11 are connected to the concentrator 12 via transmission lines 15. In this embodiment, each sensor node is individually connected to the concentrator 12 by its own transmission line 15. The concentrator in turn transmits data signals to the recorder or central recording unit 13 via transmission line 16. Thus, all the information from the various sensor nodes 11 is transmitted to the central recording unit 13 through this single cable 16.

In one embodiment, the collectors 20 of each remote sensor node 11 comprise: a digitizer of analog signals received by the sensors 10 and a transmitter of digital signals to the concentrator 12. The reflected seismic signals, which are received by the sensors 10 in analog form, are converted in the collector 20 of each node 11 before transmission to the concentrator 12. In a particular embodiment, the collector 20 comprises an ISDN-U 80-160 Kbps communications chip controlled by a FPGA/HDLC microcontroller. Power is provided through a power regulator and a transformer. The converter is a 4 - 8 channel, dual analog/digital 21 bit unit. A preamplifier and a low cut filter are provided for selectable gain. In a further embodiment, the collector 20 also comprises an up/down communication separator.

The concentrator 12 comprises a 1,000 - 10,000 channel unit. The concentrator 12 has an 80 - 160 Kbps ISDN-U interface to which each of the transmission lines 15 from the sensor nodes 11 are connected. Field programmable gate array (FPGA) control logic and protocols are used to make the bit stream look like a UNIX file. Finally, a transmitter

capable of SONET/ATM (Asynchronous Transmission Mode), OC-3 155.52 Mbit/s, transmission inputs data to the transmission line 16.

The central recording unit 13 has an ATM interface for connection to the transmission line 16. Data is transmitted from the interface over a PCI or FDDI bus to several UNIX work stations. In various embodiments, the recording unit 13 comprises a data handling and data storage work station, a user interface, operator control, basic QC work station and a seismic QC processing work station.

Referring to Figure 3b, an embodiment of the invention is shown which is similar to that shown in Figure 3a, with a modified sensor configuration. Here the sensors 10 from the different nodes 11 are interspersed so that data points may be obtained from locations across the entire survey area regardless of whether a given node 11 fails.

Referring to Figures 3a and 3b, each sensor node 11 is connected directly to the concentrator 12 by its own transmission cable 15 so that multiple nodes 11 are not lost if a single transmission line 15 fails. Each sensor node 11 is made up of sensors 10, a collector/digitizer 20 and lines 14 which connect the sensors 10 to the collector/digitizer 20. The sensors 10 comprise standard hydrophones and geophones as are known in the art. The transmission lines 14 comprise standard twisted-pair wires as is well known. The transmission lines 15 comprise AWG 24 gage, 2-wire twisted pair cables capable of carrying two-way low speed telecommunication transmission (ISDN) and power on the same twisted pair. The transmission line 16 comprises high speed transmission telecommunication technology (ATM), such as fiber optics, which is also well known to those of skill in the art.

Referring to Figure 4a, a side view of an embodiment of the invention is shown. A cable 19, which contains the component parts disclosed in Figure 1, is buried below the sea floor 17. The transmission lines are all contained within the cable 19 and are brought to a central location for connection to the concentrator 12 at the sea floor 17. Sub sea trenchers and cable laying equipment may be used to dig the trench, deposit the cable 19 and backfill the trench with earth. These technologies are well known.

Referring to Figure 4b, an alternative embodiment for coupling of the sensors to the sea floor is shown. The cable 19 is permanently attached to the sea floor 17 by pylons 21

driven into the sea floor. The cable 19 is then stretched between the pylons 21 across the surface of the sea floor 17.

In a particular embodiment, the cable 19 is 3 - 6 km long and the sensors are spaced 25 - 50 meters apart.

Referring to Figure 5, a side view of another embodiment of the invention is shown. In this embodiment, groups of the sensor nodes 11 are arranged in vertical configurations. Thus, several bore holes are drilled at various locations in the sea floor 17 so that sensor nodes 11 may be placed therein. Multiple sensor nodes 11 are placed in each borehole so that data points may still be collected from the borehole if a single node 11 fails. Again, sensors 10 from different nodes 11 are alternately positioned for redundancy. The sensor nodes 11 are connected to the concentrator 12 by transmission lines 15. The concentrator 12 is connected to the central recording unit 13 by a single transmission line 16.

Referring to Figure 6, a top view of an embodiment of the invention is shown comprising multiple concentrators and a super concentrator. Similar to the embodiments disclosed above, this configuration comprises sensor nodes 11 which further comprise a collector/digitizer 20, sensors 10 and transmission lines 14. Each of the sensor nodes 11 are individually attached to a concentrator 12 by a transmission line 15. Note that there are two concentrators in this embodiment, each being associated with different groups of sensor nodes 11. The concentrators 12 are connected to a super concentrator 23 via transmission lines 16. The super concentrator 23 is connected to the recorder 13 via a transmission line 22. This configuration is more effective in larger survey areas where transmission lines 16 and 22 must transmit data signals over great distances to the recorder 13. Other embodiments comprise multiple concentrators 12 and super concentrators 23. The size and geophysical obstacles of a particular survey area dictate the number of concentrators and super concentrators required.

Referring to Figure 7, a process outline for one embodiment of the invention is described. In the first step, signals which have been reflected by rock formations within the earth are received 701 by the remote sensors. These analog seismic data signals are converted 702 by the digitizer of each node to a digital data signal. These data signals are

then transmitted 703 by low speed transmission from each sensor node over independent transmission lines to a concentrator. At the concentrator, the remote data signals are received, stored and concentrated 704. This step comprises storing the data in a buffer and multiplexing the data for transmission. In the next step, the concentrated data is transmitted 705 over high speed fiber optic cable from the concentrator to the central recording unit. This concentrated data is then received 706 by the central recording unit and recorded 707.

Each of the above-illustrated embodiments are shown in offshore applications. However, the present invention is also applicable to land and transition zone production cites. It is to be noted that the above-described embodiments illustrate only typical embodiments of the invention and are therefore not to be considered a limitation of the scope of the invention which includes other equally effective embodiments.

I claim:

1. A process for transmitting seismic data signals from a plurality of permanent remote sensor nodes to a recorder, the process comprising:

transmitting remote data signals independently from each node of the plurality of permanently coupled remote sensor nodes to a concentrator of the data signals; and

transmitting concentrated data signals from the concentrator to a recorder.

2. A process as in claim 1, wherein said transmitting remote data signals comprises low speed transmission.

3. A process as in claim 1, wherein said transmitting remote data signals comprises transmitting signals over electrically conductive wires.

4. A process as in claim 1, wherein said transmitting concentrated data signals comprises transmitting signals over fiber optic lines.

5. A process as in claim 1, further comprising digitizing the seismic data signals at each node of the plurality of permanent remote sensor nodes.

6. A reservoir monitoring system for conducting long-term seismic surveys, the system comprising:

a plurality of permanently coupled remote sensor nodes;

a concentrator of signals from said plurality of permanently coupled remote sensor nodes; and

a recorder of concentrated signals from said concentrator.

7. A system as in claim 6, wherein each of said plurality of permanently coupled remote sensor nodes comprises a plurality of seismic sensors and a digitizer of analog signals.

8. A system as in claim 7, wherein seismic sensors from first and second sensor nodes from said plurality of permanent remote sensors are permanently positioned such that a sensor of the first node is between two sensors of the second node.

9. A system as in claim 6, wherein said concentrator comprises a receiver of low speed data signals and a transmitter of high speed data signals.

10. A system as in claim 6, wherein said concentrator is installed at ground level.

11. A system as in claim 6, wherein said recorder comprises a receiver of data signals and a recorder of data signals.

12. A system as in claim 6, further comprising a plurality of remote transmission lines which independently connect each of said plurality of remote sensor nodes to said concentrator.

13. A system as in claim 12, wherein said remote transmission lines comprise electrically conductive wires.

14. A system as in claim 6, further comprising a transmission line which connects said concentrator to said recorder.

15. A system as in claim 14, wherein said transmission line comprises a fiber optic cable.

16. A reservoir monitoring system for conducting long-term seismic surveys, the system comprising:

a plurality of permanently coupled remote sensor nodes, wherein each node comprises a plurality of seismic sensors and a digitizer of analog signals;

a concentrator of signals received from said plurality of permanently coupled remote sensor nodes;

a plurality of remote transmission lines which independently connect each of said plurality of remote sensor nodes to said concentrator;

a recorder of concentrated signals from said concentrator; and

a transmission line which connects said concentrator to said recorder.

17. A system as in claim 16, wherein each of said plurality of remote sensor nodes comprises a plurality of seismic sensors and a digitizer of analog signals.

18. A system as in claim 17, wherein seismic sensors from first and second nodes of said plurality of seismic sensors are permanently positioned such that a sensor of the first node is positioned between two sensors of the second node.

19. A system as in claim 16, wherein said concentrator comprises a receiver of low speed data signals and a transmitter of high speed data signals.

20. A system as in claim 16, wherein said recorder comprises a receiver of data signals and a recorder of data signals.

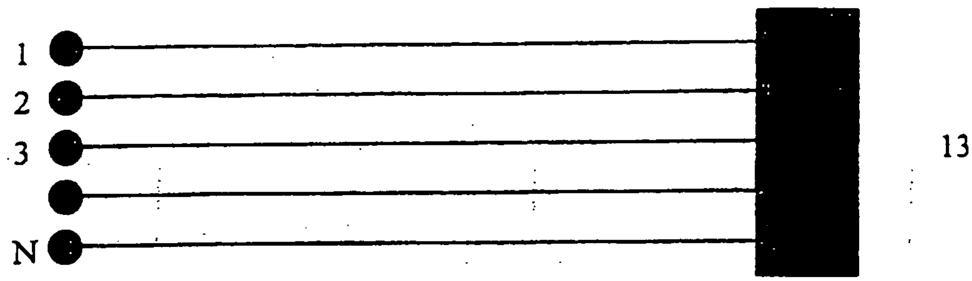

Figure 1

(Prior Art)

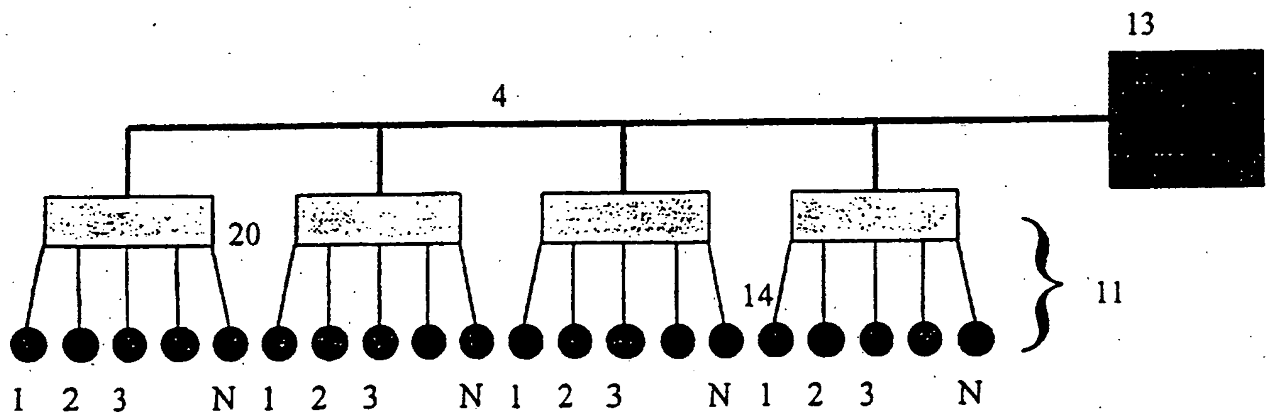

Figure 2

(Prior Art)

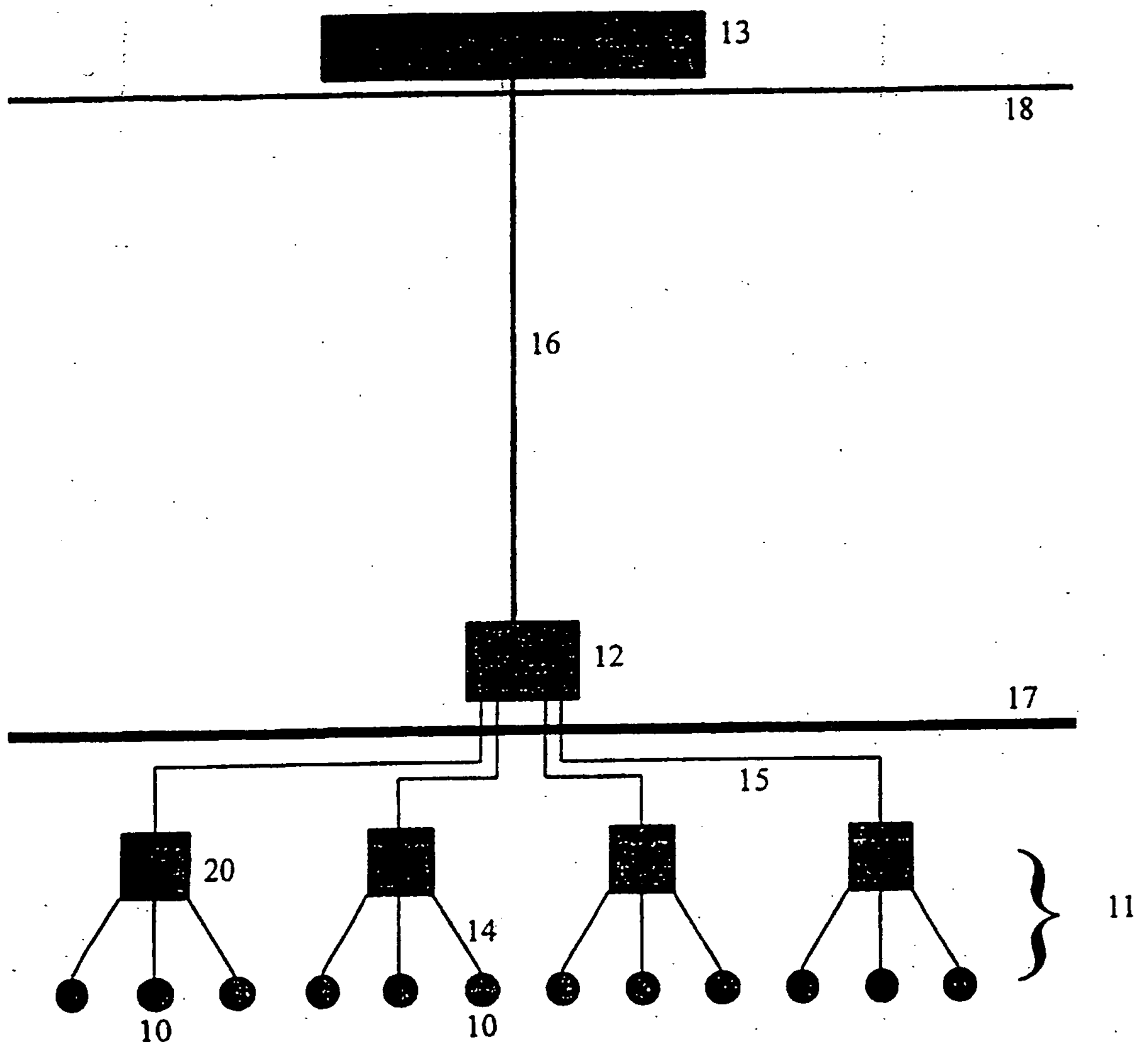

Figure 3a

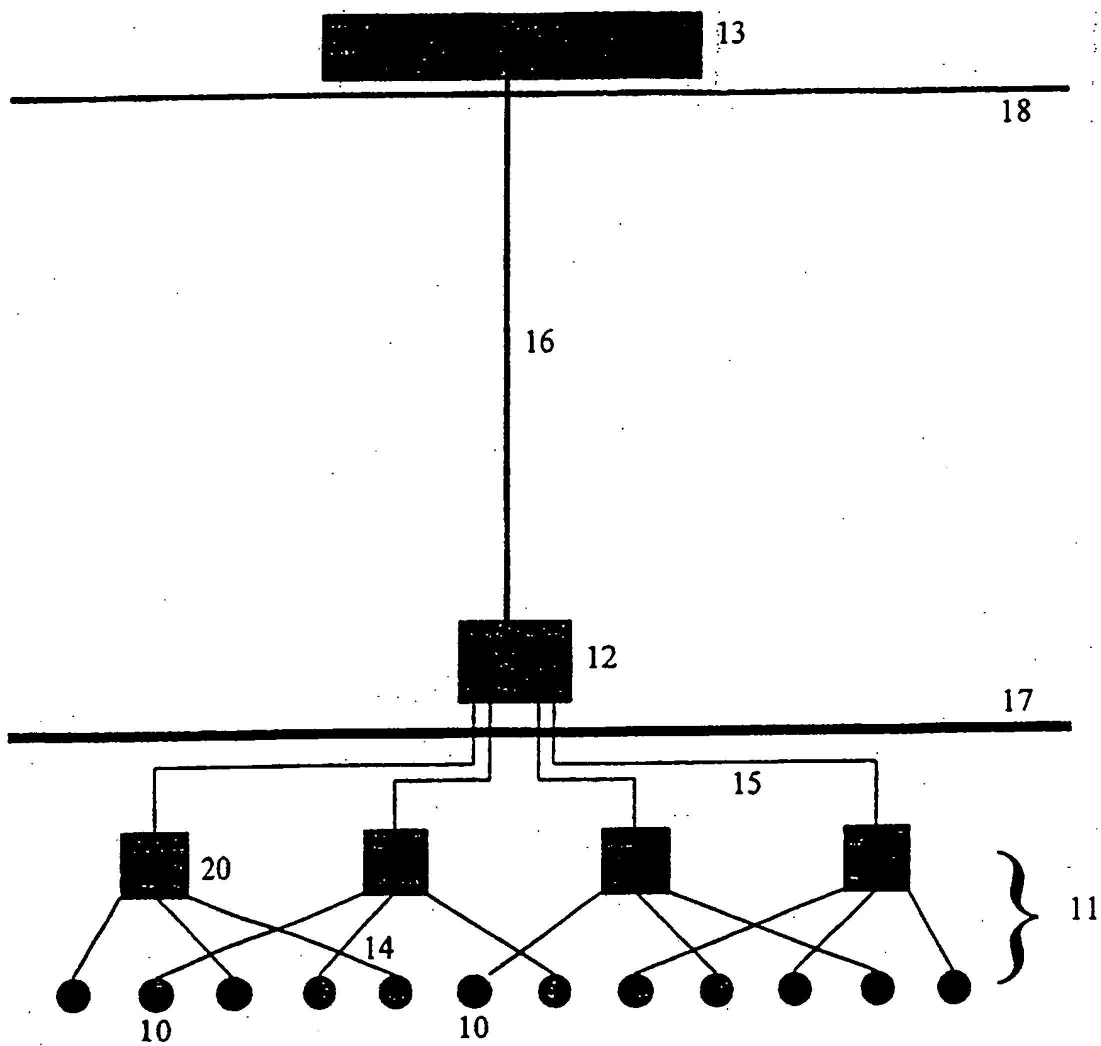

Figure 3b

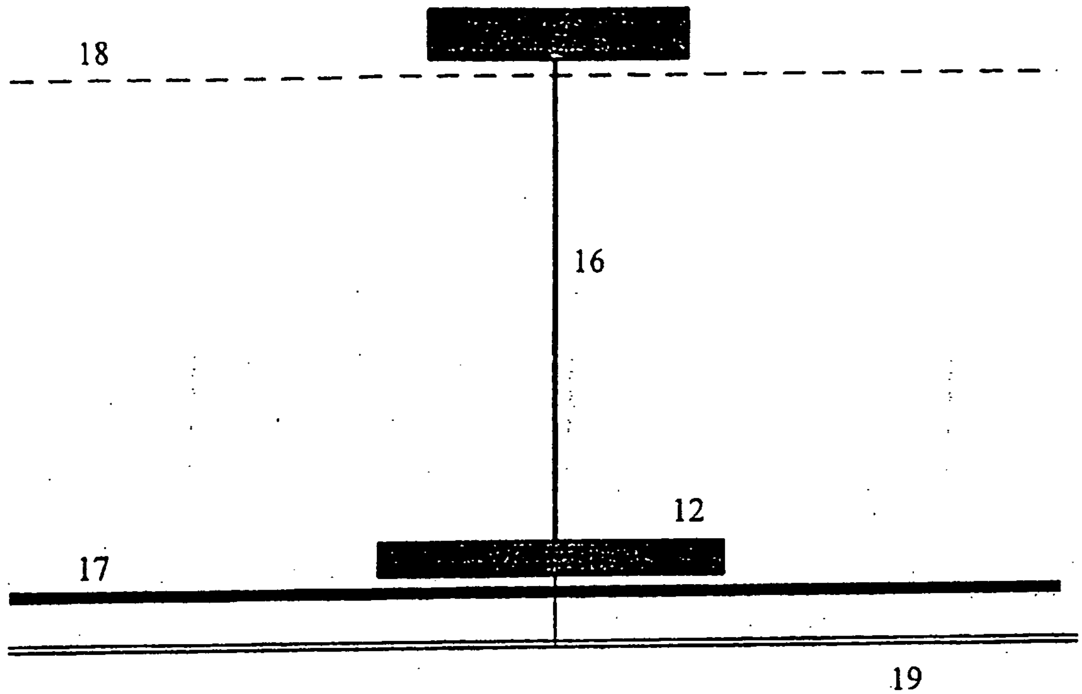

Figure 4a

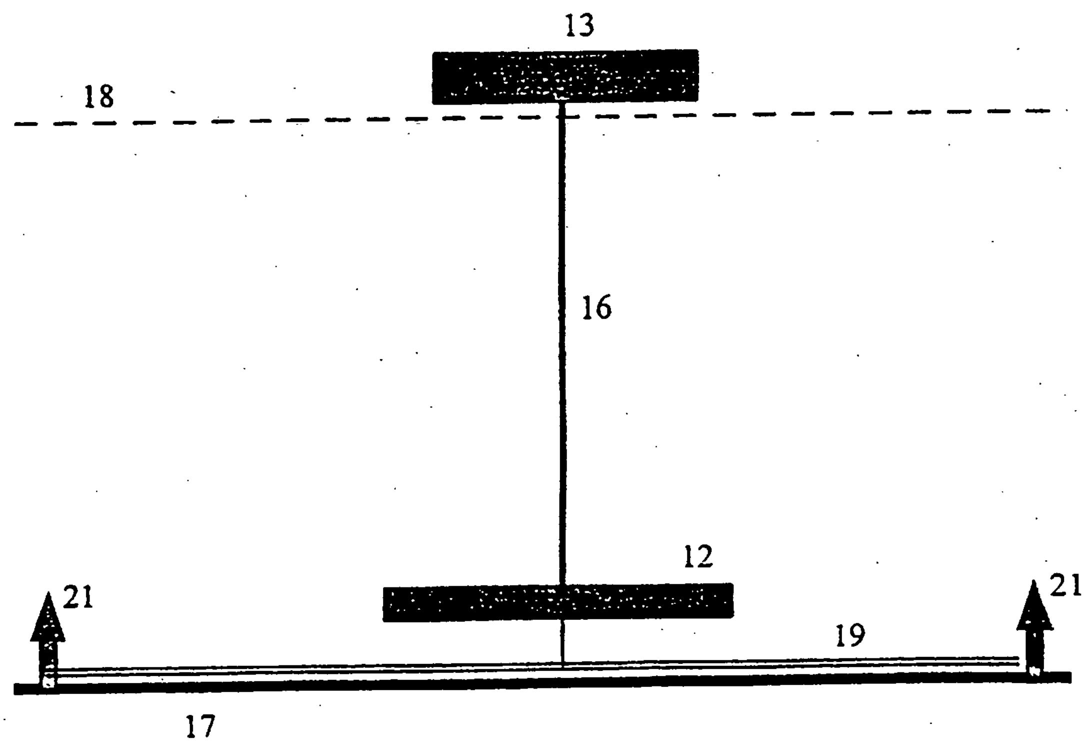

Figure 4b

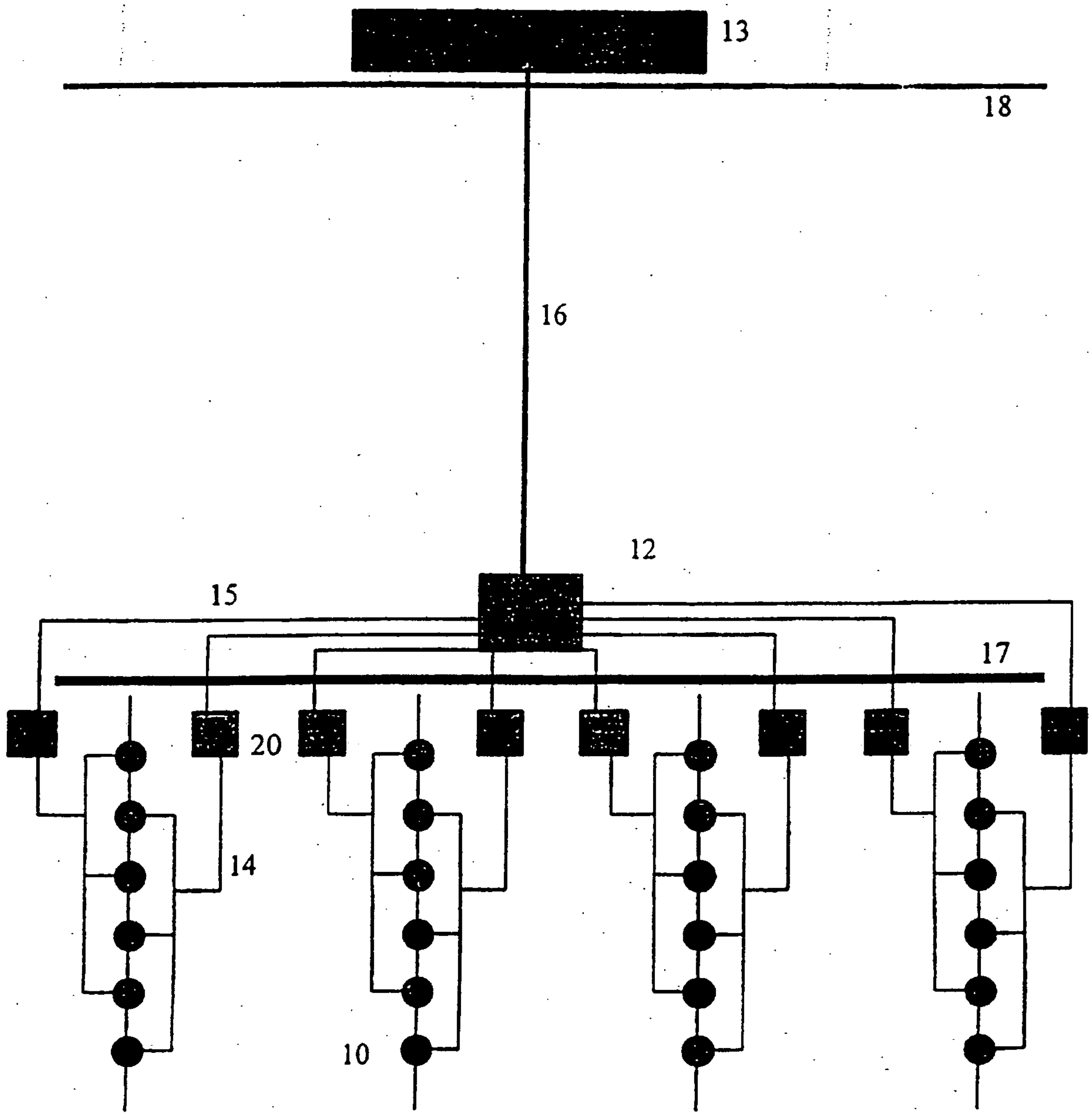

Figure 5

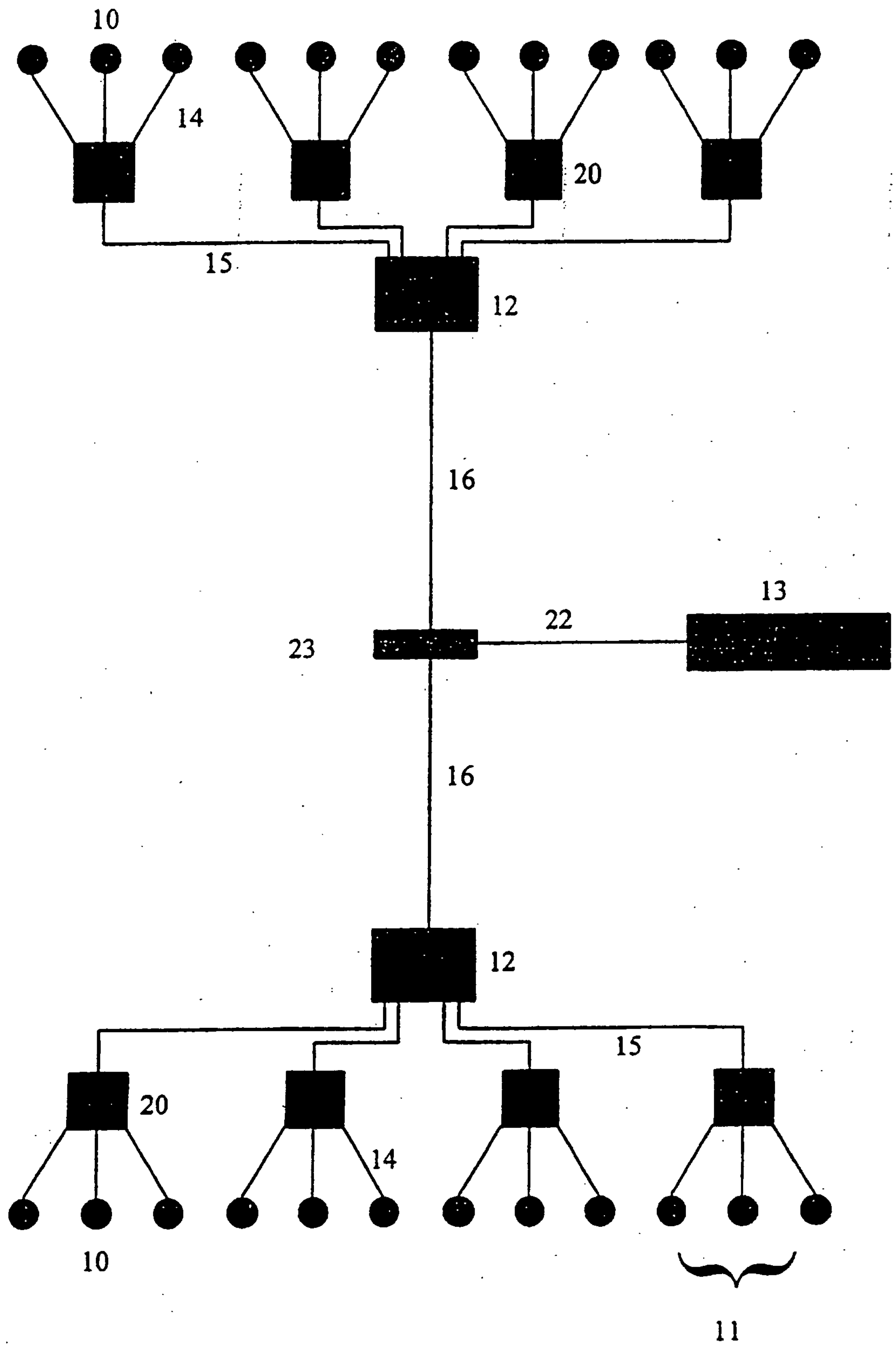

Figure 6

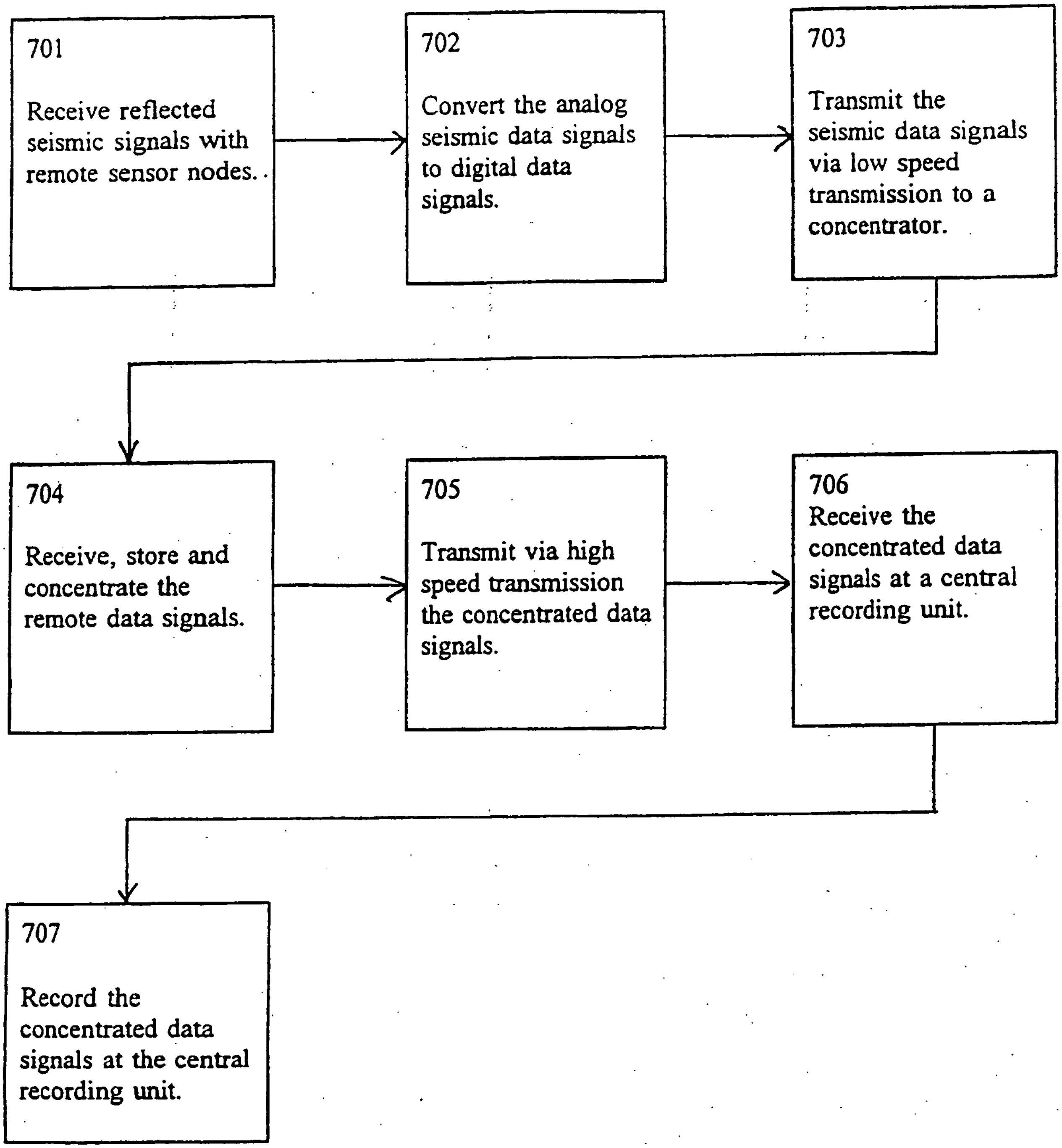
701
Receive reflected seismic signals with remote sensor nodes.
702
Convert the analog seismic data signals to digital data signals.
703
Transmit the seismic data signals via low speed transmission to a concentrator.
704
Receive, store and concentrate the remote data signals.
705
Transmit via high speed transmission the concentrated data signals.
706
Receive the concentrated data signals at a central recording unit.
707
Record the concentrated data signals at the central recording unit.

FIGURE 7